The Cyclope: A 6 DOF Optical Tracker Based on a Single Camera

Hervé Mathieu

The Cyclope: A 6 DOF Optical Tracker Based on a Single Camera

Hervé Mathieu[1]

(1) PERCEPTION group - INRIA Rhône-Alpes
655 avenue de l'Europe – ZIRST Montbonnot – 38334 Saint Ismier cedex
herve.mathieu@inrialpes.fr

Abstract

In this paper we describe a low-cost infrared optical device capable of tracking two targets with six DOF (Degrees Of Freedom) for interaction within both desktop and large projection applications. We use off-the-shelf components for the hardware and open-source libraries for the software.

Keywords: Virtual Reality, Human-Computer Interaction, Optical Tracking

1. Introduction

Computation of the position and orientation of a target (target pose) using images of markers (passive infrared reflectors) when the geometric configuration of the target is known has important applications such as calibration, navigation, tracking and object recognition.

For the last decade several optical systems have shown their efficiency to achieve this task like the NDI Optotrak (North Digital web site) and the ART ARTTrack (ART web site). All these systems are based on two or more video cameras. Such a system suffers from the limited field of view, bounded to the intersection of the camera's field of view, and from the need to have an accurate registration between the different cameras. At the end we have a costly device. At the opposite very-cheap optical trackers are now appearing on the consumer market like the NaturalPoint OptiTack (NaturalPoint web site). They are designed for the video game market. Their performances are poor because they implement low-quality components.

We present here a new affordable device (CYCLOPE web site), with suitable performances for virtual reality applications. The innovation introduces by the CYCLOPE is that it is based on a single camera, and implements state-of-the-art algorithms developed in the computer vision community. Industrial off-the-shelf components are used, thus providing a high-quality device.

2. System Description

The CYCLOPE concept relies on the following problem: Given the 3D positions of 4 non coplanar points, and their 2D positions in the image, retrieve the position and the orientation (Pose) of the reference frame attached to the 3D points with respect to the camera reference frame.

We do not detail here the state-of-the-art algorithms solving this problem. Among the existing algorithms, we select the Pose algorithm described in (De Menthon and

Davis, 1995) because of: (1) its fast convergence allowing a frame rate implementation, (2) its robustness, i.e. the capability to deliver the good solution when it exists, (3) its Matlab and OpenCV (OpenCV web site) implementations available, making the algorithm fast to test and fast to implement.

We describe in the following section the hardware and the software parts of the CYCLOPE (*Figure 1*, *2*).

Figure 1. The CYCLOPE device.

Figure 2. Workbench and CYCLOPE.

Hardware

All optical trackers are more or less based on the same technology. The whole system consists of three sub systems:

- Passive reflective markers are spheres with a diameter between 10 and 25 millimeters. They are coated with reflective paper. To build a 3D target, 4 spheres must be fixed on a rigid structure.
- The tracker itself is composed of three elements: (1) an infrared flash based on LED, (2) an infrared filter to cut the visible bandwidth, and (3) a video camera. The video camera is an industrial camera with FireWire output, B&W sensor, VGA resolution, and external trigger capability.
- A standard PC running either Windows or Linux and providing a FireWire input. The PC can be either a dedicated PC or the PC implementing the virtual reality application.

Software

The software relies on both open-source and proprietary libraries. The codes are written in C language. The whole program is composed of three processes. The main process implements the user interface and the Pose computation. It relies on the OpenCV library. The acquisition process is based on the CMU 1394camera (CMU 1394camera web site) interface for the Microsoft Windows platform, and it is based on the OpenCV FireWire camera interface for the Linux platform. The communication process provides the results to the final application. It implements a simple UDP based protocol, thus allowing any other program to connect to the CYCLOPE. A VRPN (VRPN web site) CYCLOPE class is delivered as open-source, and acts as a communication code example.

3. Performances

The performances of the CYCLOPE can be described by the following attributes: working area, frequency and latency, accuracy, and robustness.

- The working area is bounded by the cameras' field of view. For the current hardware version, the working area is 60 degrees by 56 degrees. The maximal working depth is reached when the spheres are not well detected in the image. Depending on the conditions (Light, sphere diameters) it is around 5 meters.
- The CYCLOPE tracker runs at a frequency of 60 Hertz on a PENTIUM IV PC. The intrinsic latency is less than 30 milliseconds.
- The accuracy in position and orientation was measured using high-precision linear and rotation stages. The RMS (Root mean Square) errors obtain for a standard configuration (Spheres clearly detected in the image, depth range up to 1.5 meters) are less than 1 millimeter in translation and less than 0.3 degree in rotation.
- The robustness was evaluated by two preliminary tests. We run the systems in a non-friendly environment to test the limits. For instance we add some noisy lighting. Then we run the system for days long.

4. Conclusion and Future Work

We have developed a low-cost device for virtual reality applications. The system is usable in the current version, and an advanced contact has been engaged with an industrial company to make the CYCLOPE an off-the-shelf product. The next software version will implement a Kalman filter in order to reduce potential noise in the tracking output. The CYCLOPE could be extended in two directions:

- Increase the number of spheres attached to the 3D target. This will improve; (1) the visibility of the 3D target by increasing the probability that the camera detects a sufficient number of spheres, and (2) the accuracy of the tracking.
- Covering a wider area by using several CYCLOPE devices. Intrinsically, several CYCLOPE devices can work together out of their common field of view.

5. References

De Menthon and Davis, 1995: Model-Based Object Pose in 25 Lines of Code. *International Journal of Computer Vision,* pp.123-141.

ART web site: http://www.ar-tracking.com/

CMU 1394camera web site: http://www.cs.cmu.edu/~iwan/1394/

CYCLOPE web site: http://www.inrialpes.fr/sed/6doftracker/

NaturalPoint web site: http://www.naturalpoint.com/

North Digital web site: http://www.ndigital.com/

OpenCV web site: http://www.intel.com/technology/computing/opencv/index.htm

VRPN web site: http://www.cs.unc.edu/Research/vrpn/